Marco Polo
An Asteroid Sample Returns to Earth

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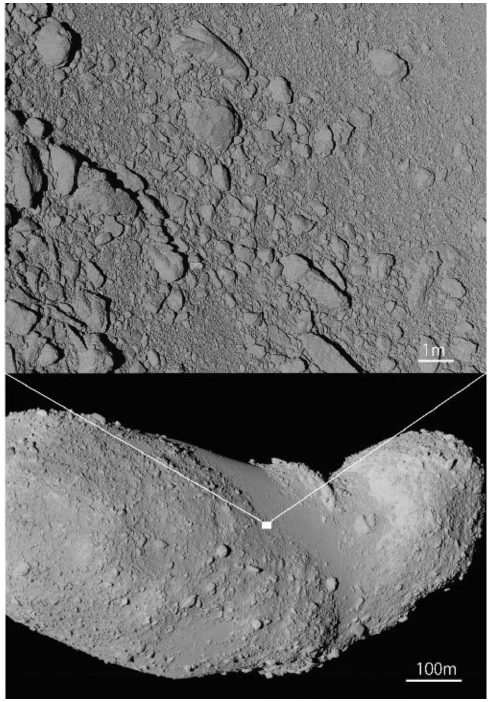
Outline

- The Mission
- The Spacecraft
- The Earth Re-Entry Capsule

The Mission

Asteroids

- Extremely primitive bodies – “fossils”
  - Leftover from the formation of the solar system
  - History and processes of solar system/planetary formation
- Future resource utilisation
  - NASA flexible path plan
- Earth impact threat
  - Structure and composition must be understood before a deflection attempt can be made
- Currently of great interest to scientists



Marco Polo Science Case

- Candidate mission for ESA's Cosmic Vision
  - 12 month assessment study led by Astrium
- Aim to obtain a sample of asteroid surface material and return it safely to Earth
- Fundamental questions:
  - What were the properties of the building blocks of the terrestrial planets?
  - What are the organics in primitive materials?
  - What is the role of impacts by NEOs in the origin and evolution on Earth?
- Significant step in our understanding of the solar system

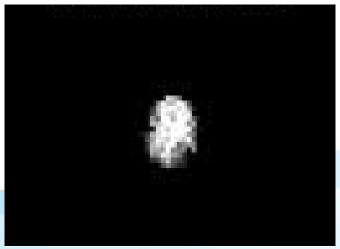
Mission Requirements

- Obtain a sample of 30-100g asteroid regolith
  - Preferably from 5-10 cm below the surface
  - Some pebbles highly desired

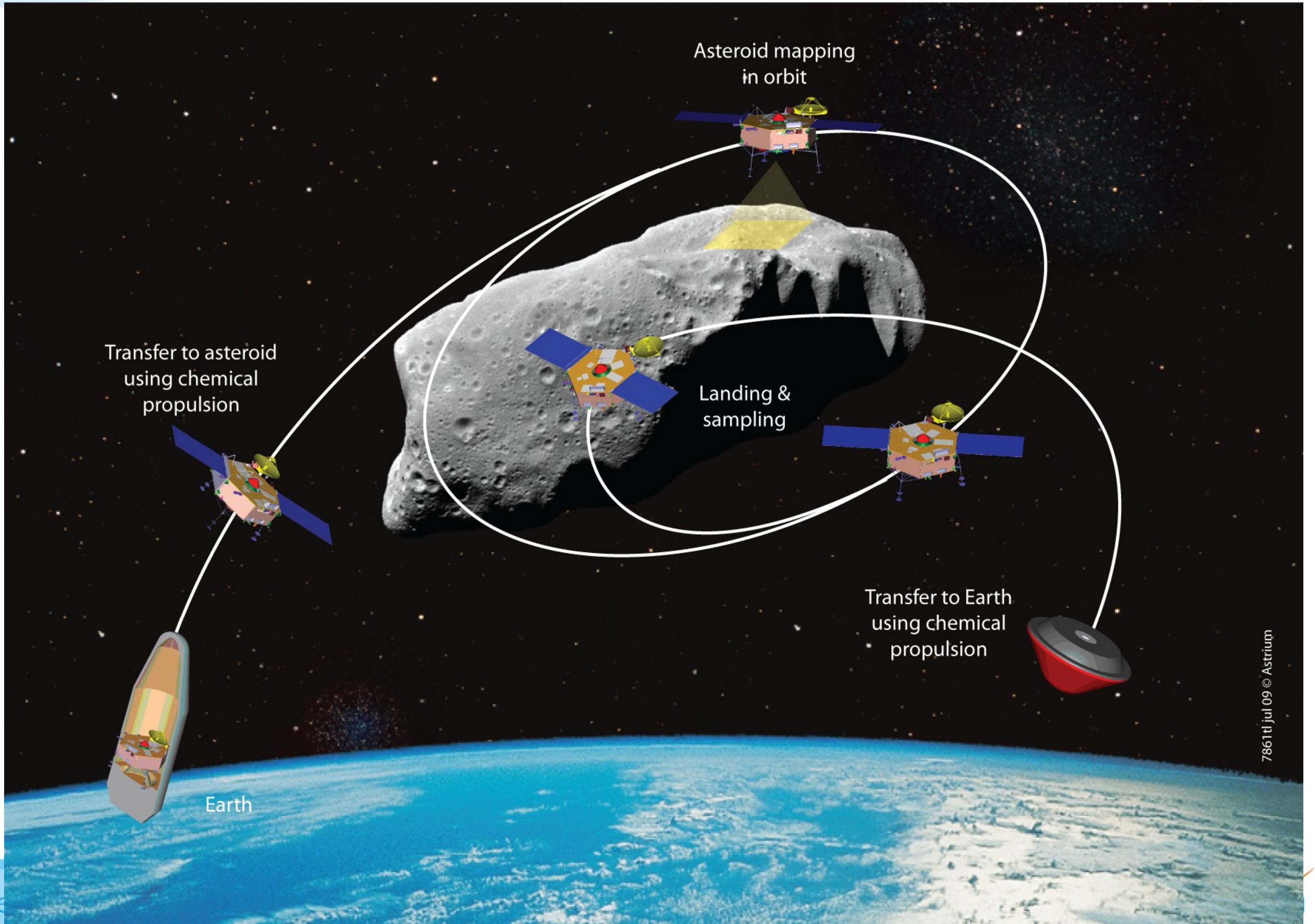
- In-situ science instruments
  - Narrow, wide angle and close-up cameras
  - Radio science experiment, Vis/Near-IR and Mid-IR spectrometers, laser altimeter and neutral particle analyser
- Launch in 2017-2018
  - Soyuz launcher preferred, max mission duration of 8 years
- Many mission architectures studied (>50)
  - Single landing spacecraft with chemical propulsion selected
  - Earth Re-entry Capsule (ERC) attached to landing spacecraft
  - Lowest cost and mass mission with low risk implementation

Asteroid Target

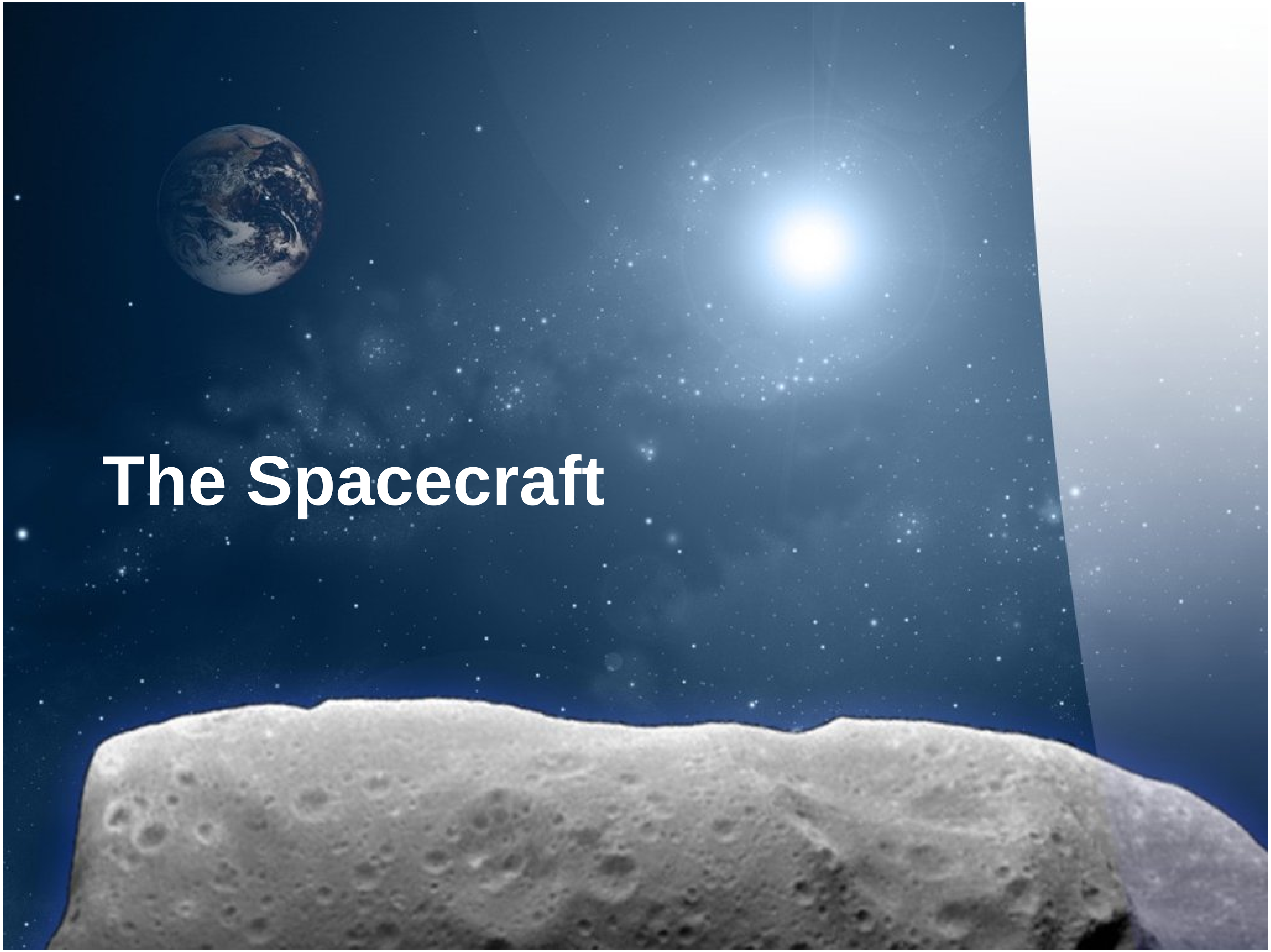
- 1999 JU3 selected as target after detailed analysis
  - Very primitive class of asteroid (C-class)
  - Low delta-V required – minimum of 2599 m/s
- Physical properties:
  - Small diameter of 780 m and mass of 3E+11 kg
  - Very low gravitational environment
  - Fast rotation period of 7.7 hours
  - Eccentric orbit: Perihelion = 0.9 AU, Aphelion = 1.42 AU
  - Maximum temperature at perihelion = 399 K
- Highly challenging environment for a spacecraft to visit!



Mission Design

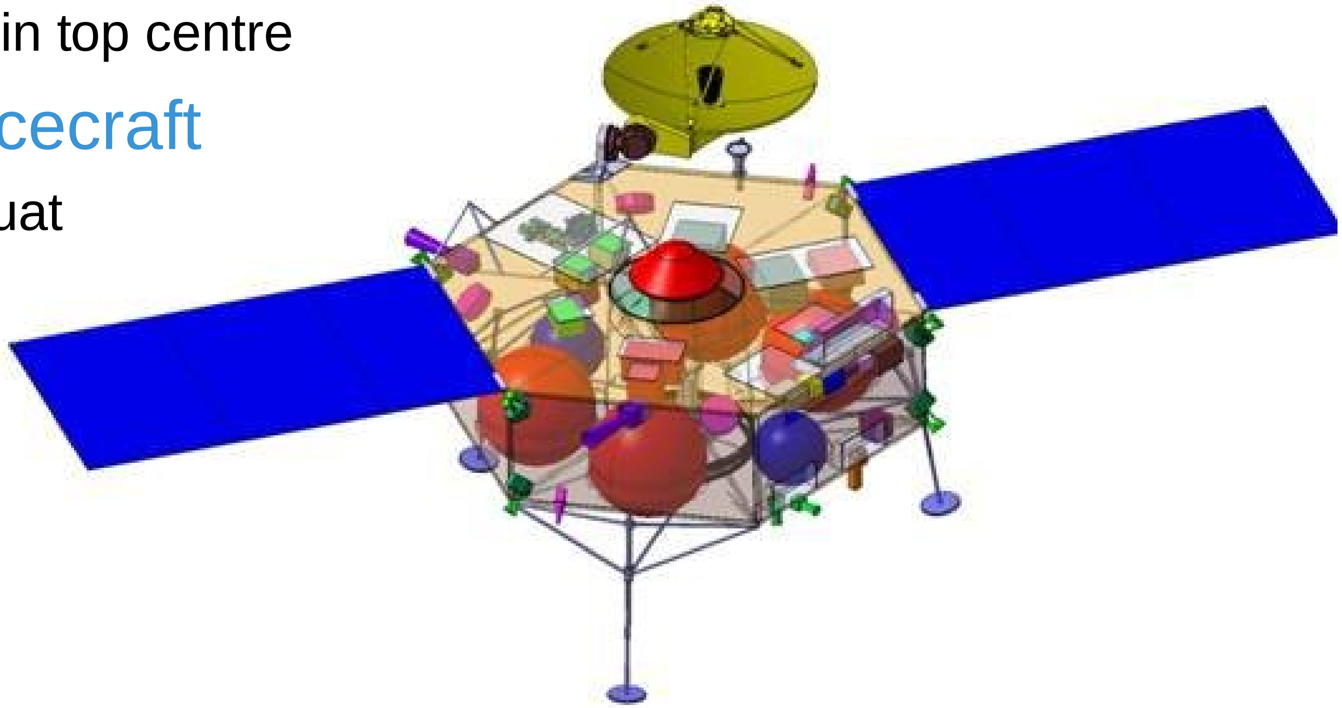


The Spacecraft



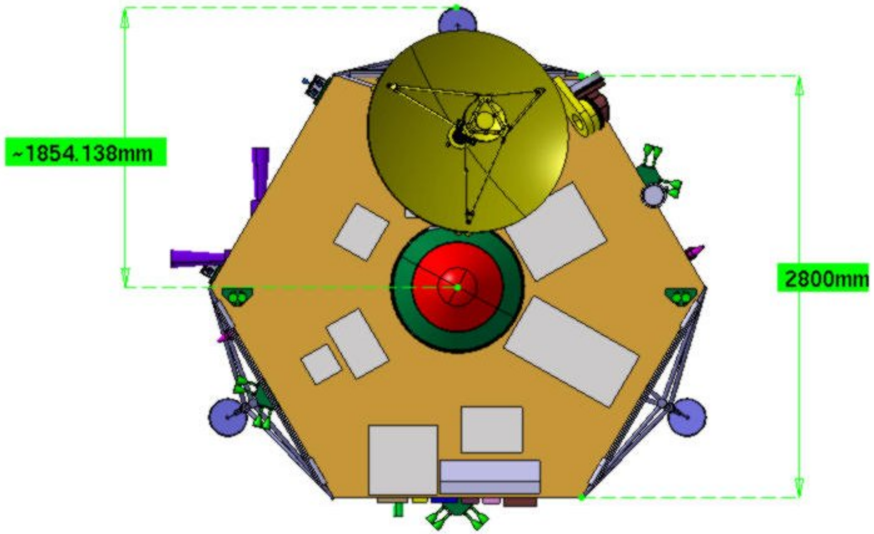
Spacecraft Reference Design

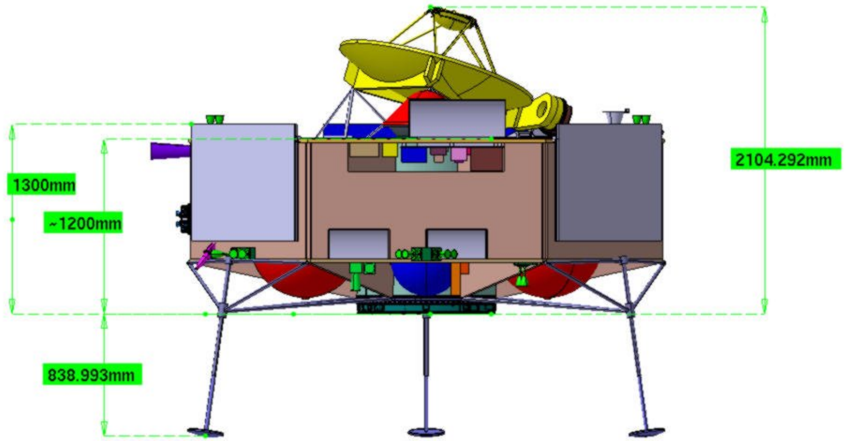
- 3-axis controlled landing spacecraft
  - Can land on any illuminated side of the asteroid
  - Hexagonal structure with radial shear walls
  - Two folding solar arrays
  - Three landing legs absorb impact energy
  - Steerable high gain antenna and medium gain antenna
  - ERC located in top centre
- 4 m wide spacecraft
  - Short and squat
  - Low CoG



Spacecraft Reference Design

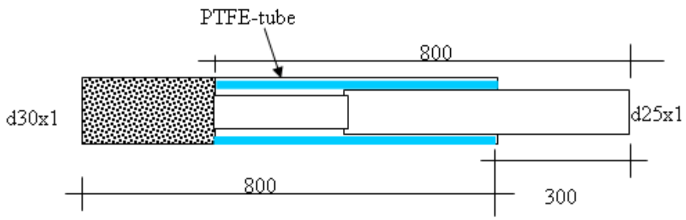
- Central cylinder
  - Based on LISA Pathfinder
  - Robot arm and sampling mechanism stowed here
- Two hexagonal floors attached
  - Lower floor: propulsion system, landing gear, landing sensors
  - Upper floor: remote sensing payload and avionics
  - Allows parallel integration and test of mechanical platform and avionics ‘flatsat’

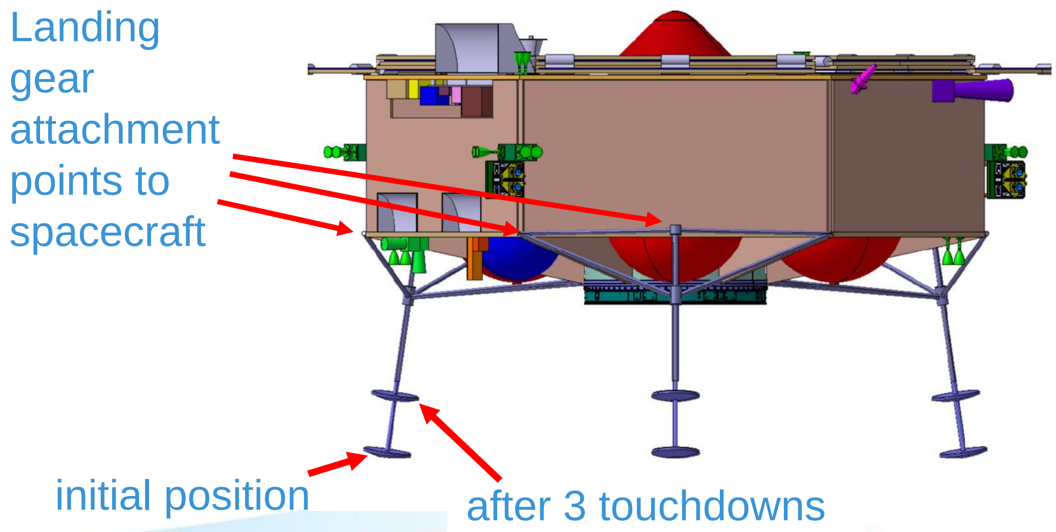




Landing Legs

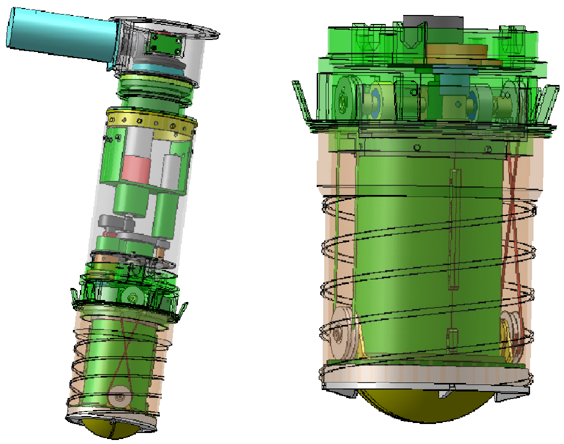
- Plastic buckling selected to absorb impact energy
  - Unidirectional carbon/glass fibre tubes with crushable R31 cell material inside
  - Piston tube with circular landing pad guided within tube
  - Crushable material will crush up to 10 cm on each landing attempt absorbing impact energy

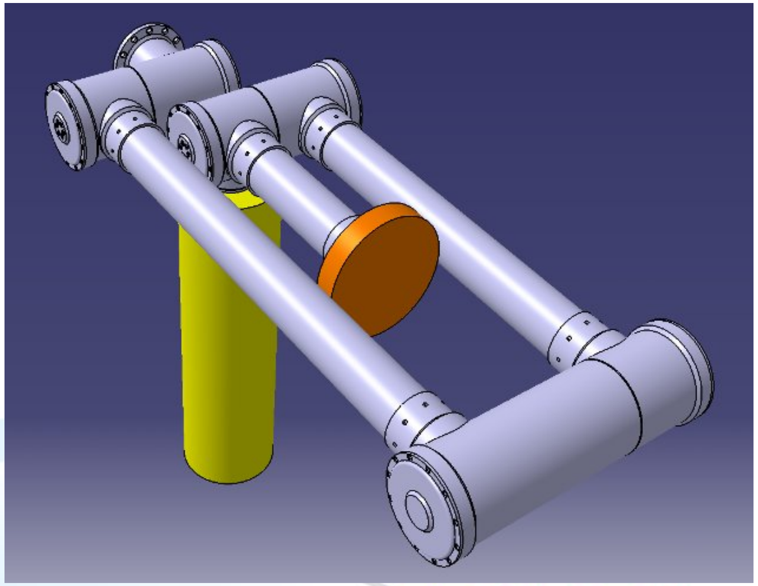




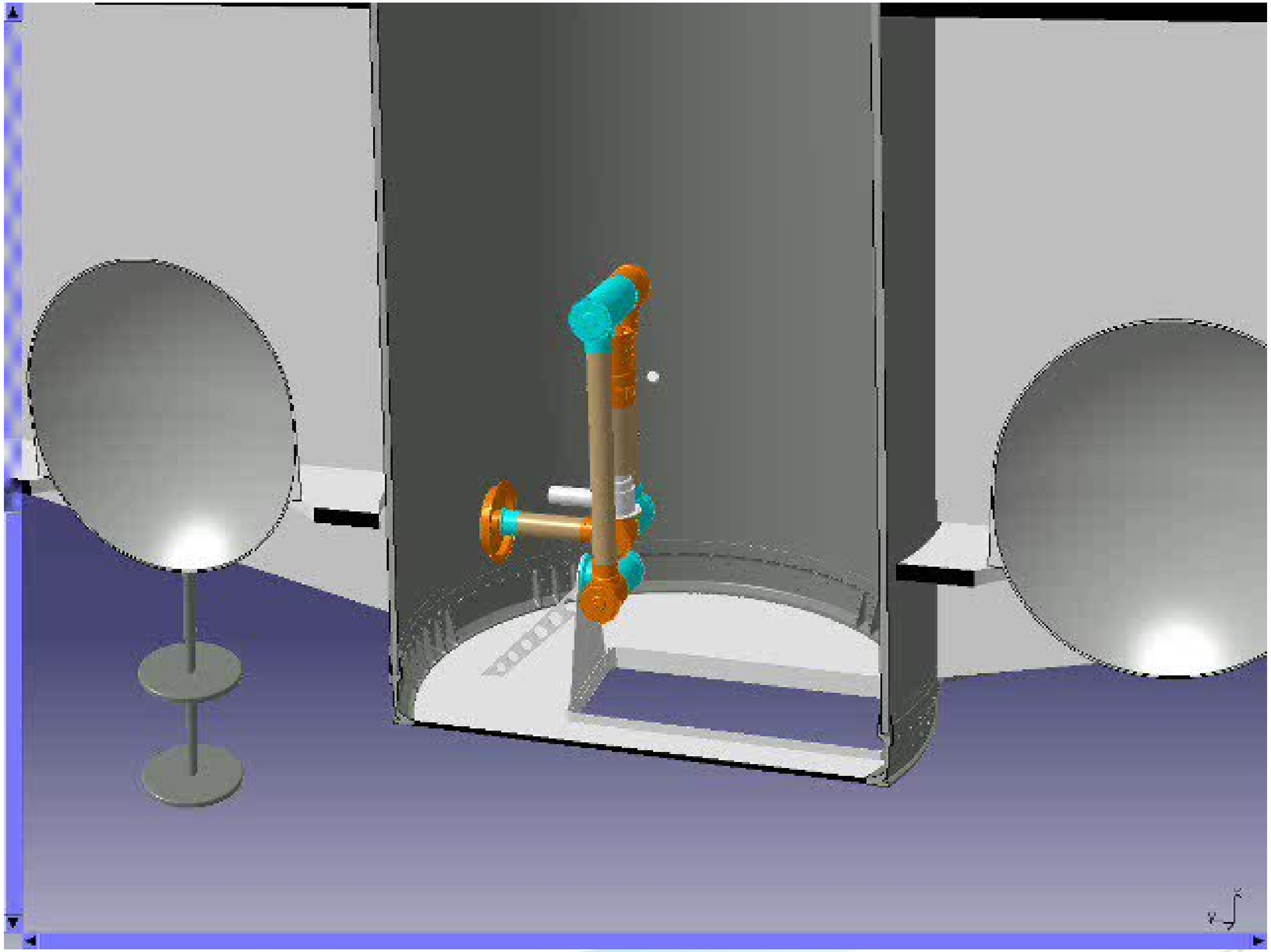
Sampling Mechanism

- Rotating corer mechanism
  - Attached to end of robot arm
  - Located in central cylinder
  - Can obtain sample up to 89 cm^3
  - Closure doors over end to retain sample
  - Mandrel (tool drive) provides rotation
  - Breakable sensing wires verify sample
- Robotic arm transfers sample
  - 3 DOF and 3 rotational joints
  - Clip mechanism seals sample within container
  - ERC closure lid protects sample



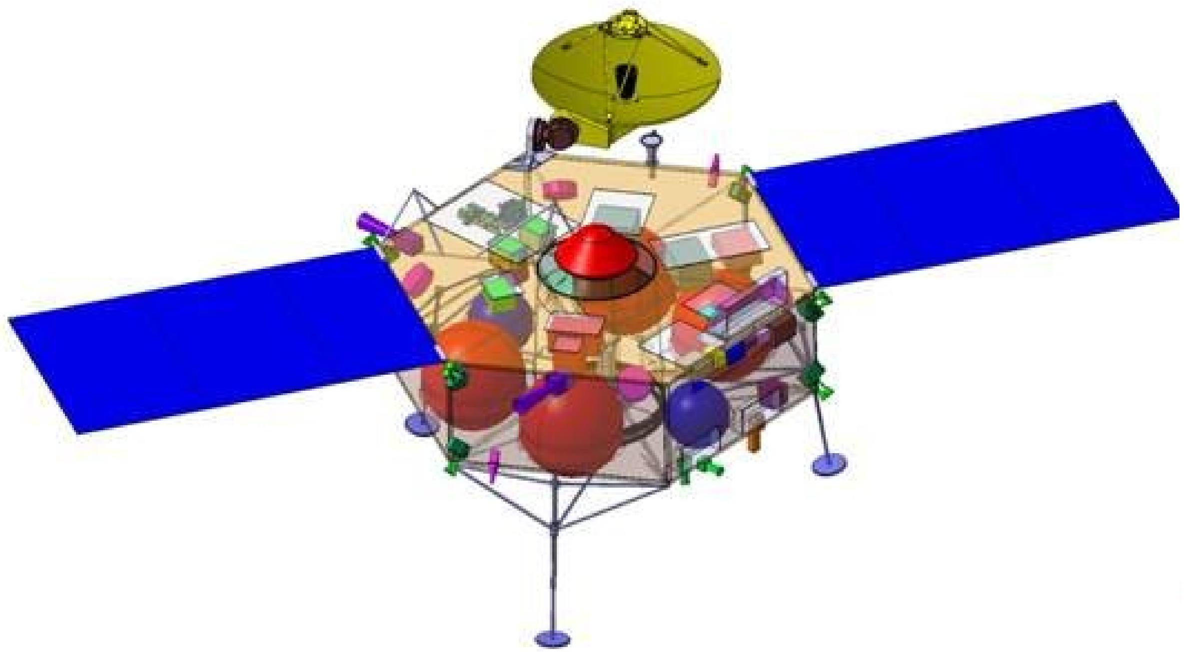


Sample Transfer



Spacecraft Mass

- Overall composite spacecraft mass:
  - Wet mass = 1408 kg
  - Dry mass = 745 kg
- Margin of 13% achieved with Soyuz launcher
- Additional 20% system margin on top of this



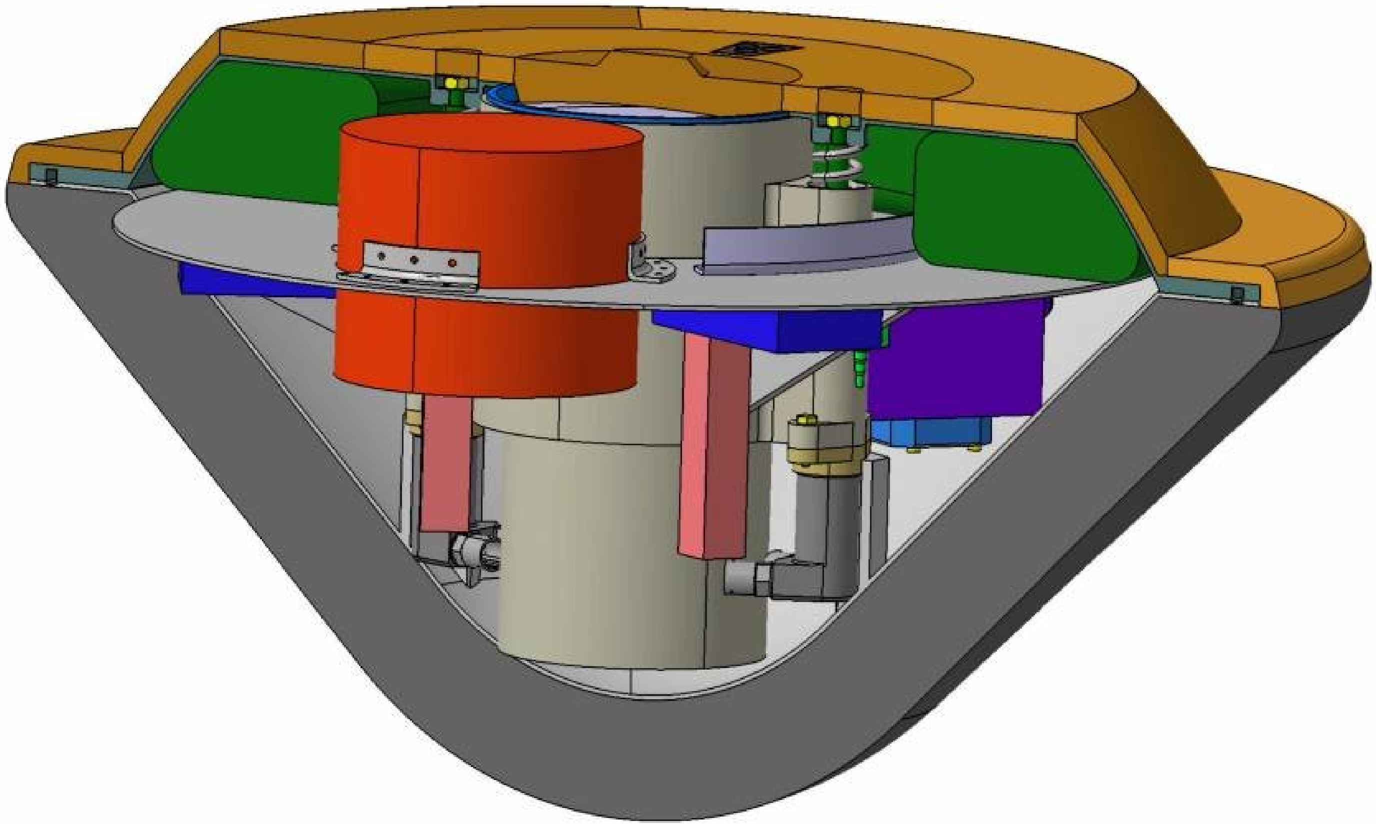

The Earth Re-entry Capsule

ERC Design Drivers

- Main design drivers:
  - Hayabusa-type design preferred by ESA
  - Re-entry velocity of 12.1 km/s
  - Mass of 20-30 kg
  - Diameter of 500-600 mm
  - Sample container volume allocation of 100 mm diameter and 200 mm length
  - Maximum g-loads to the sample of 200g (25 Hz) & 800g (100 Hz)
  - Provide a recovery time of ~ 5 days
- RadFlight-like aeroshape selected
  - Stability and extensive aerodynamic database available
  - Favourable volume-to-size ratio

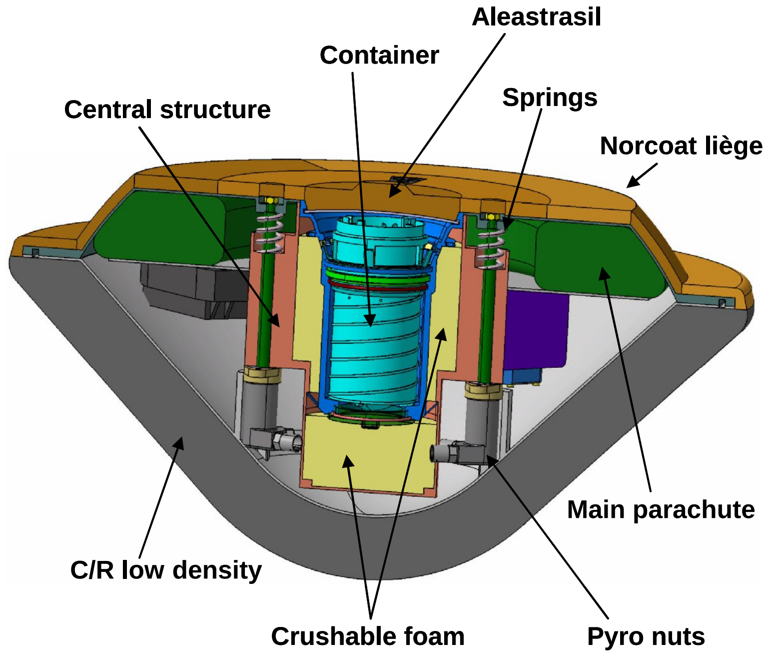
ERC Reference Design

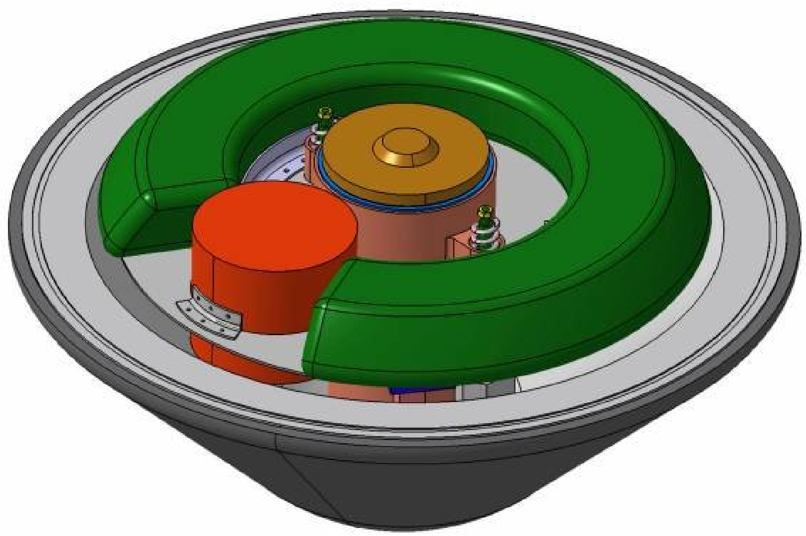
- Half-cone angle of 45 °
- Homothetic nose radius of 180 mm
- Diameter of 600 mm
- Mass = 26.3 kg



ERC Reference Design

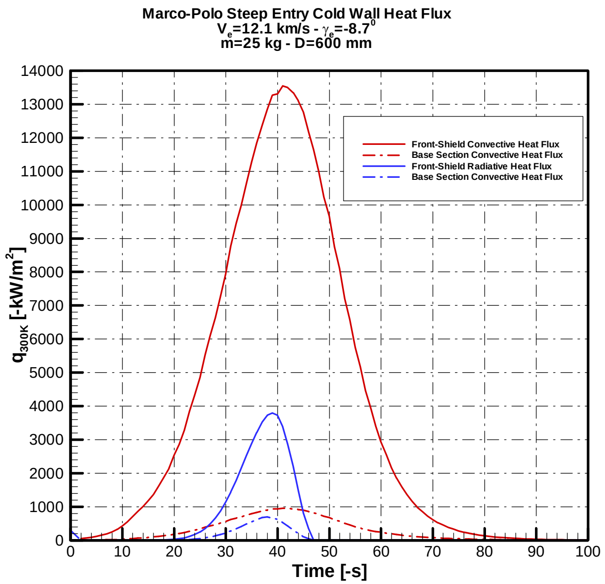
- Thermal Protection System
  - ASTERM for frontshield
  - Norcoat liege for back cover
  - High density TPS on door
- Aluminium structure
- Two parachutes
  - Pilot and main
- Pyro nut separation mechanism
- Dampers to attenuate shocks
- Crushable material (TBD)
  - Attenuate landing impacts
- Equipments:
  - Battery, beacon, accelerometer, central electronics unit





Re-entry Trajectory Assessment

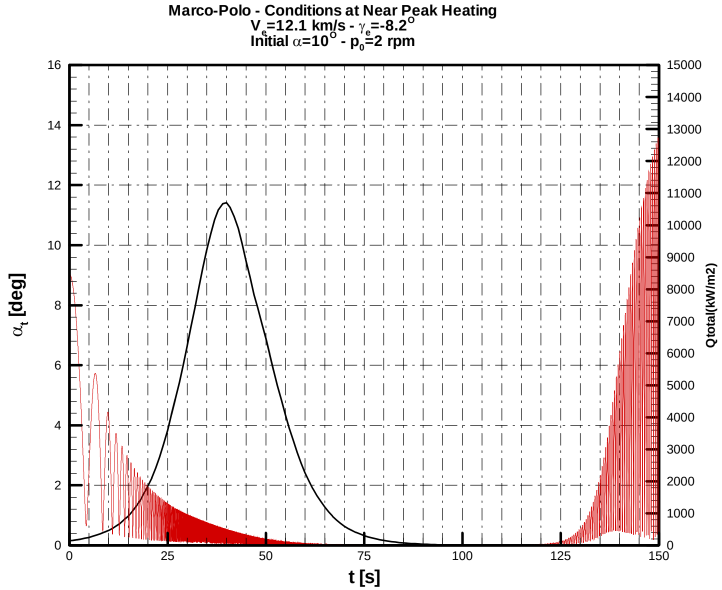
- Maximum heat flux to ERC = 18 MW/m^2
  - Includes 100% margin for radiation and 20% for convection
  - 50 mm thick TPS required on heatshield
- At 120 km altitude and 12.1 km/s re-entry velocity:
  - Heading angle must be 115 ° W/SW and latitude 30 ° S
  - FPA driven by peak heat flux and g-load
  - Sizing FPA range of -8.7 ° to -7.7 °
- Analysis of heat flux experienced:
  - Frontshield ~ 17 MW/m^2
  - Back cover ~ 1.5 MW/m^2
  - Total energy = 330 MJ/m^2 at stagnation point
  - Re-entry duration = 1100 seconds

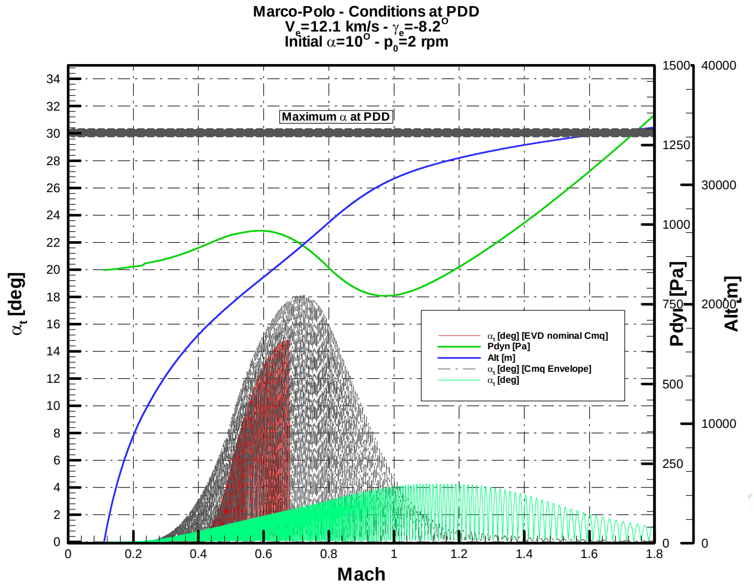


Re-entry Stability Assessment

- ERC jettisoned with 2 rpm spin
  - Angle of attack set at 9 °
- ERC is stable during supersonic phase (M > 3)
- Unstable when M < 1.4
  - Angle of attack divergence of 18 ° amplitude
  - Dynamic instability of capsule

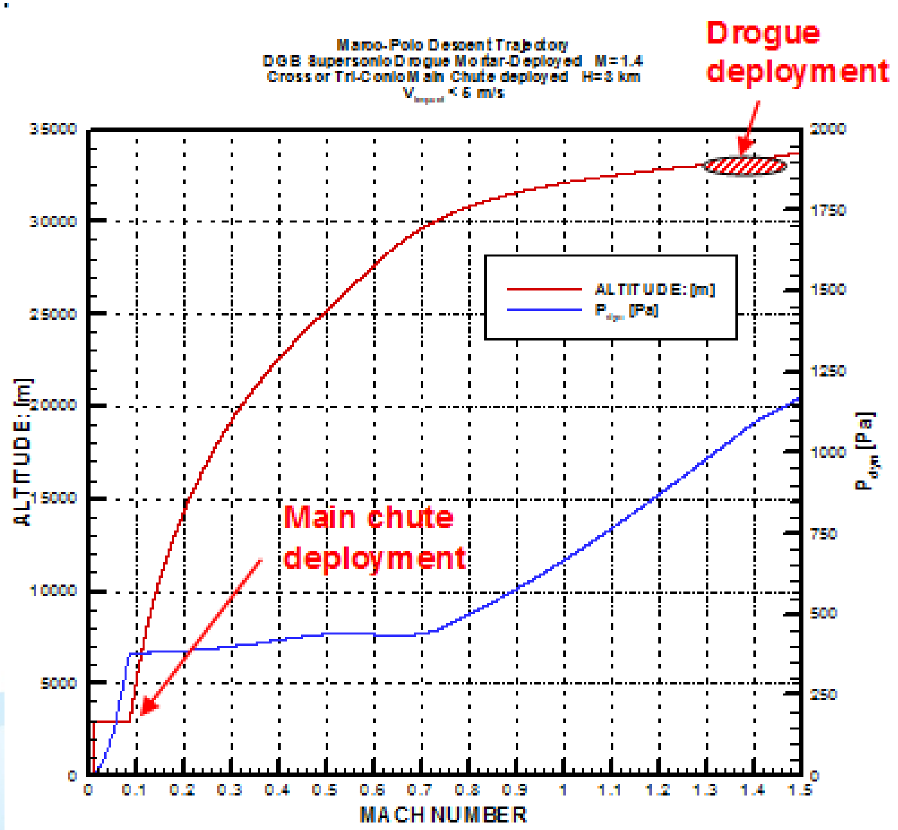
=> Supersonic pilot chute necessary for stabilisation
  - CoG should also be moved forward with ballast





Descent Sequence

- Two-stage parachute system necessary for deceleration and stabilisation
  - 0.8 m diameter pilot chute (Disk-Gap-Band) deployed at M = 1.4
  - After timed 500s, pilot chute pulls off back cover
  - 5.3 m diameter subsonic parachute then deployed (~ 3km altitude)
    - Deployed late to minimise landing ellipse
  - Total mass = 4 kg including mortars
- Vertical speed at impact is 5 m/s



Summary

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- Marco Polo Assessment Study successful
  - Resulted in an innovative and efficient mission design
  - Launch margin of 13%
- Design and analysis of the ERC shows two-stage parachute is necessary for stability and impact load requirements
  - Descent would protect the pristine asteroid sample
- Marco Polo not down-selected by ESA at this stage but still highly desired by scientists


Questions